Operation of an Open Path Infrared Gas Analyzer Developed at the Atmospheric Turbulence and Diffusion Division

David L. Auble

Introduction

This document describes the operation of an open path H_2O/CO_2 infrared gas analyzer (IRGA) developed at ATDD. The instrument measures atmospheric fluctuations of water vapor and CO_2 densities from O to 20 Hz. Instrument power requirements, signal outputs, mounting considerations, calibration, maintenance, and diagnostics are discussed.

Power Requirements

The power source must be 10.5 to 15 volts D.C. with a capacity of 3 amps. NOTE: Some IRGA power supplies will operate from 9 to 36 volts. Be sure to confirm that the supply is configured for the extended voltage input range before applying more than 15 volts.

The cable with the three pin female connector should be connected to the power supply module. This cable id referred to as the "power cable." The power cable wires are:

Red wire:	Connect to +12 volts
Black wire:	Connect to 12 volt return (common or ground)

Instrument Cable

The heavy grey cable with a 18 pin female connector on each end is referred to as the "instrument cable." It connects the power supply module to the sensor head. The instrument cable carries power from the power supply module to the sensor head and returns the signal outputs from the sensor head to the power supply module. This cable is limited to a maximum length of 6m.

Signals

The cable with the six pin male connector is referred to as the "signal cable." It should be connected to the power supply module. The wire definitions of the signal cable are:

Red wire:	H20 output
Green wire:	CO2 output
White wire:	Sensor body temperature
Black wire:	Common
Shield wire:	Ground

(the shield wire is either bare or brown)

Mounting

The sensor head should be mounted with the connector downward. Mounting the instrument at an angle of approximately 5° from vertical will help keep water from pooling on the windows. The power supply module should be mounted with connectors downward if exposed to weather, but may be mounted at any angle if protected from rain.

When mounted on a moving platform or a fixed platform subject to vibration , special care should be taken to isolate the instrument from the vibrations. Vibrations. Vibrations cause excessive noise in the output.

Output Description

The H_2O and CO_2 outputs can vary over a ± 13 volt maximum range. They are capable of sourcing or sinking 10 mA. The output ranges are usually adjusted so that they should stay within**xx** volts under normal operating conditions, but may be adjusted to accommodate most data acquisition systems' voltage input ranges. The CO_2 concentration is often very high due to breathing. If adjustments must be made to the output range, there are adjustment potentiometers inside the sensor head (see below).

The outputs are nonlinear, however they may be assumed linear over a small range. Since atmospheric CO_2 concentrations are normally in a small range centered around 350 ppm, a linear calibration of CO_2 is initially provided. The output of the CO_2 channel is volts vs. mg/m3 H_2O. Both signals may have some offset drift. so it is best to ignore the absolute number and only consider fluctuations.

The temperature output is a voltage that represents the internal temperature of the sensor head. The temperature output will be between 0.2 and 1.55 volts in a normal operation. voltages above 1.55 volts may indicate that it is too hot. The actual internal temperature is ˚C =(28.1*V)-8.

The shield wire is directly connected to the sensor head chassis. It is resistively and capacitively coupled to the output common. Depending on the data acquisition system being used and the method of sensor head mounting, the shield wire could be connected to either earth ground or signal common. In general, if the data acquisition system being used has differential inputs, the shield wire should be connected to signal common.

Output Adjustments

The output voltage range for H_20 and CO_2 may be adjusted if necessary. By referring to the Board 1 schematics (Appendix A) or photos (Appendix B), the locations of the various potentiometers for offset and span range may be found. Be very careful not to turn any other potentiometers, since the operating characteristics of the instrument could be adversely affected. The output offset and span potentiometers are:

R11: H_20 Offset
R12: H_20 span (or gain)
R14: CO_2 offset
R15: CO_2 span (or gain)

Calibration

CO_2 calibrations may be performed by covering the instrument with a calibration hood, sealing the hood to the instrument base using vinyl (electrical) tape, and pumping standard calibration mixtures (Airco or Scott specialty gases, CO_2 in air) into the hood. Typically concentration standards of 330 and 370 ppm are used. Zero gases will usually be off-scale. The temperature and pressure of the calibration gas inside the hood must be measured to obtain gas density (mg/m3) from concentration (ppm). Ambient pressure may be used if the gas flow-rate is low or zero.

Typically, a large flow rate (2-4 l/min) is used to purge the calibration hood (approximately 2 minutes or until stable CO_2 output is reached), then reduced to less than 1/2 l/min, and readings of gas temperature, pressure, and CO_2 output are taken. Field calibrations are generally easy to perform.

H_2O calibrations may be performed by using a cylinder of dry air and a water bubbler, a mixing system, and a chilled mirror hygrometer. Different mixtures of saturated and dry air, ranging from nearly dry to nearly saturated, should be pumped into the calibration hood. The dew-point, temperature, pressure, and IRGS H_2O voltage should be recorded. A second order polynomial regression of g/m^3 H_2O vs IRGA H_2O may be performed to fit a calibration curve through the data points. A LI-COR dew point generation system (model LI-610) may also be used for H_20 calibrations with dew points above ˚C. Some useful equations for converting units may be found in Appendix C.

Output offset drift in the H_2O output should be considered. A voltage offset change will change the position on the calibration curve, resulting in a different slope. The best way to determine water vapor sensitivity is to have an independent measure of water vapor concentration based on an absolute method (chilled mirror, wet/dry bulb, etc.), calculate absolute humidity from the measurement (g/m^3), then refer to the calibration chart to find the sensitivity. An alternate method involves using the polynomial calibration coefficients. Two values must be determined from the data set: X_{REF} and V_x. These are defined as:

X_{REF} = Reference humidity measurement in g/m^3 H_2O

V_x = H_2O voltage output of the IRGA at humidity X_{REF} (in volts)

These calibration points may be carefully checked single points or short time period (about half-hour) averages. Using these two values, a quantity V_{REF} should be calculated:

$$V_{REF} = \frac{-b + \sqrt{b2 - 4a(c - X_{REF})}}{2a}$$

where

V_{REF} = what the voltage should be at the reference humidity based on the laboratory Calibration, and

a,b,c = the quadratic coefficients of the laboratory second order calibration,

i.e.,

$$X(g/m^3) = aV^2 + bV + c$$

where

V = the voltage output from the sensor.

A linear calibration may now be determined:

$$m = 2aV_{REF} + b$$

$$B = X_{REF} - (2aV_{REF} + b)(V_x)$$

$$X(g/m^3) = mV + B$$

Maintenance

Under normal operating conditions, the IRGA requires very little maintenance. Check the mirrors and windows for excessive contamination. Silver colored mirrors may be cleaned with reagent grade alcohol (or distilled water) and a soft cotton cloth, using as little pressure as possible. Gold colored mirrors should never be touched with solid objects. Use only a jet of alcohol or distilled water from a squirt bottle. The sapphire windows may be cleaned with any glass cleaner.

Occasionally check the alignment of the optics. Place a small strip of white paper over the 1/2" flat mirror. Make sure the filament image is approximately centered over the mirror. Place the paper over the detector window (the one not lit up). A 1/2" spot of light should be visible approximately centered over the window.

Remove the finned cover and check the O-ring seals. They should be free of nicks and lubricated with a silicon based grease. Also check for any sign of moisture inside the chassis or underneath the sapphire windows.

Trouble Shooting

A Brief description of the operation of the IRGA is given in Appendix D. Understanding the IRGA operation is beneficial to diagnosing problems. A more theoretical description of instrument operation may be found in "An open path, Fast Response Infrared Absorption Gas Analyzer for H_2O and CO_2"[n1].

Make sure all cables are connected properly, and that power is applied. The LED on the power supply circuit board should be on.

Open the sensor head by removing the flat head screws and sliding the finned cover off the chassis.

Check the internal cables for loose connections. Make sure that Board 1 is seated properly on Board 2, underneath.

Check to see if the bulb is lit. If it is not, check to see if it has power. The bulb voltage is available on Board 3, P6 (see Appendix A for board Schematics and layouts).

Check to make sure the instrument has power. Three test points on Board 1 allow easy access to the ± 15 volts. Check the red, black, and white test points. Black is common; red is +15 volts; white is -15 volts. If the ± 15 volt supply is not present, check the power supply. Check the 5 volt supply available on pins 4 and 5 of P2, Board 3.

Check to make sure the filter wheel is spinning. If it is not, check for a physical problem (something binding or jammed). The small motor driving the filter wheel will wear out eventually. If the filter wheel spins freely, and 4.5 to 5 volts is present on Board 3, P5, the motor may need to be replaced. Motor replacement is described in Appendix E.

Check the detector cooler current. This is available as a voltage on Board 3, P3. It should be between 0.06 and 0.25 volts. If the instrument is too hot, the thermoelectric cooler for the detector may not be able to reach the temperature set point. The thermoelectric cooler control circuit will limit the current supplied to the cooler to about two amperes. If the control circuit is in the current limiting mode, the instrument outputs will become erratic.

The voltage across the two test points on Board 3, TP1 and TP2, represents the detector temperature. The voltage should start about 5 to 6 volts on power-up, and slowly fall to about 4.5 volts. After two minutes of operation, the voltage should reach a very steady value of about 4.5 volts.

Advanced Diagnostics and Adjustments

To thoroughly check the IRGA electronics, a dual-channel oscilloscope must be used. The time base should be 2 ms/div, and the channel inputs 5 v/div, D.C. coupled. Ground the oscilloscope to the black test point on Board 1. Attach the external sync input to the reset photo pick-up output (see board 2 schematic, Appendix A , or photos, Appendix B), The upper pin of the three pin molex connector may be used to acquire this signal. Attach the two oscilloscope channels to the reset pick-up output (also the external trigger input) and sample pulse output. The sample pulse is available at TP8, Board 1. They should look like the waveforms shown on the timing diagram (Appendix F). The reset pulse frequency should be about 45Hz(17 ms period). This is set sample/hold amplifiers should appear as shown in the timing diagram. All of these signals should be available even if Board 1 has been removed.

Attach one input of the oscilloscope to the detector output test point, Board 1, TP1. The signal should look like the detector amplifier output waveform shown in the timing diagram. The gain and offset of the detector output may be adjusted with R5 and R9, Board 1, respectively. Under normal circumstances they should not require adjustments, but R5 can sometimes be accidentally turned when removing or replacing the finned cover. The voltage range of the detector amplifier output should be between 9 volts. Adjusting the detector amplifier gain and offset should be done with the calibration hood over the sensing volume, with dry air flowing through it. If adjustments are made, set the minimum voltage at -7.5 volts and the maximum voltage at 7.5 volts. This should set the first peak height at around 10 volts (with respect to the minimum voltage).

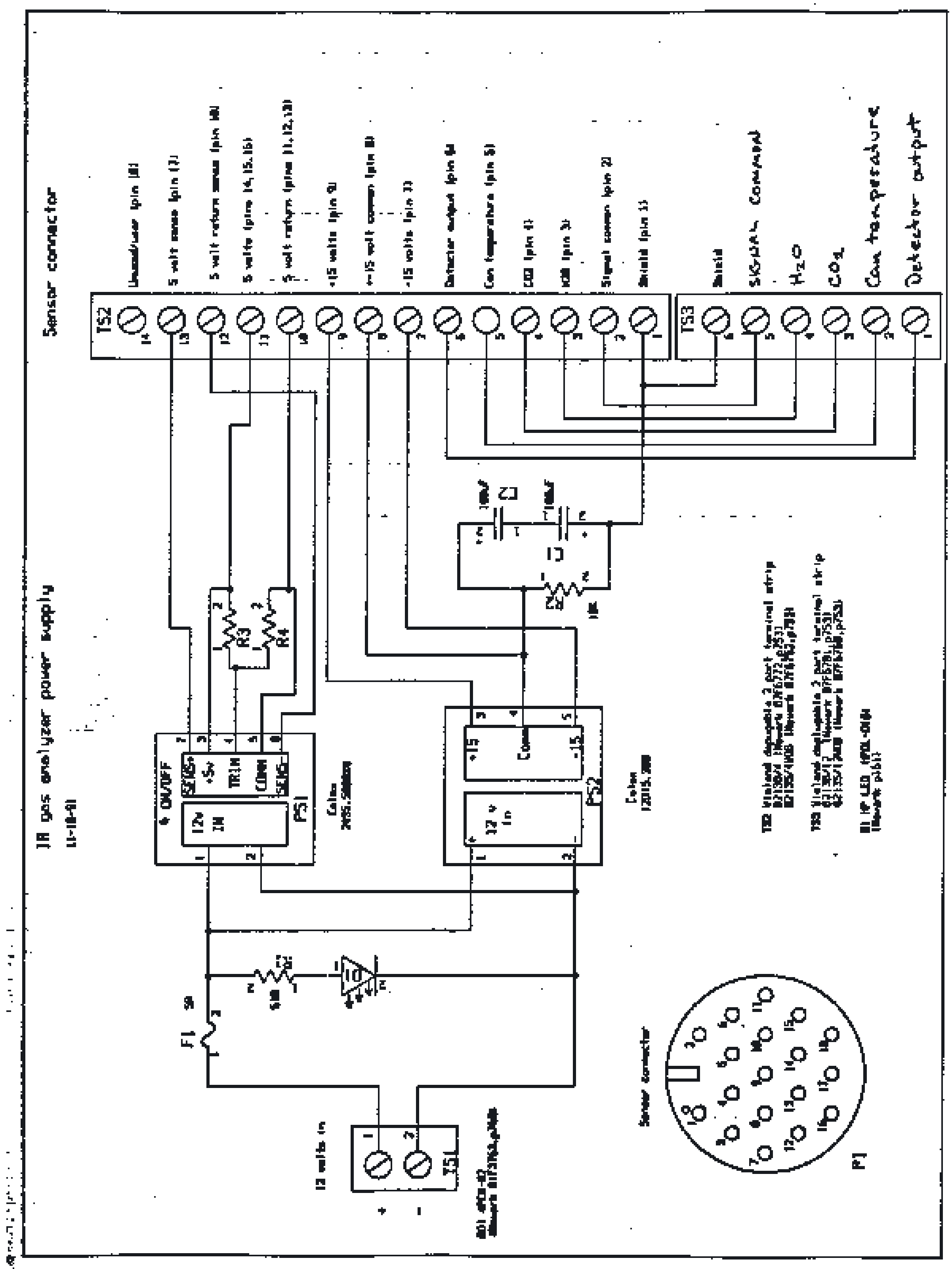
The sample/hold amplifiers may be tested by checking their outputs with one oscilloscope channel while observing the detector amplifier output with the other. The outputs of the sample/hold amplifiers, as shown on the second schematic of Board 1, should correspond with the high and low levels of each of the three peaks.

The H_2O attenuation potentiometer should attenuate the differential H_2O sampled voltage so that it is always less than the reference sampled voltage. This may be checked by purging the sample volume with dry air (using the calibration hood), and checking the numerator (H_2O) voltage and the denomination (reference) voltage to the H_2O ratio amplifier, U8, Board 1. The demonator voltage (pins 1 and 2) should be about 10 volts, and the numerator voltage should be under 10 volts, but greater than 8 volts. R16, Board 1, may be used to adjust the numerator voltage. The CO_2 attenuation adjustment (R17, Board 1) should be fully counter-clockwise.

Temperature compensation is does as an iterative process. Two calibrations must be performed: One with the instrument body cool (can temperature voltage approximately 1 volt), and one with the instrument body warm (can temperature voltage approximately 1.4volt). It should be then be determined if the can temperature change had a positive or negative effect on the output offset. Positive effects require more negative temperature amplification or less positive temperature amplification, with the reverse true for negative temperature effects on the output offset. The temperature compensation amplifiers can be individually configured for either negative and positive gain, selected by a jumper. Jumper pins 1 and 2 of P6 or P7, Board 1, for gains of +0.5x can temperature to $-\infty$ x can temperature. Jumper pins 2 and 3 of P6 or P7, Board 1, for gains of +0.5 x can temperature to ∞ x can temperature. Most instruments require a small negative gain for the H_2O channel and small positive gain for the CO_2 channel. The temperature compensation voltages are available at pins 8 and 14 of U2, Board 1, for H2) and CO_2, respectively.

The optical alignment may be adjusted for maximum signal output. If the bulb filament image is not centered on the 1/2" mirror, the bulb mount may have shifted. Loosen the bulb mount screws and adjust the position so that it is centered on the mirror. Rotating the bulb inside the mount will often move the image slightly. If the round light sport is not centered on the detector window after the center mirror adjustment was made, a complete realignment may be necessary (see appendix G).

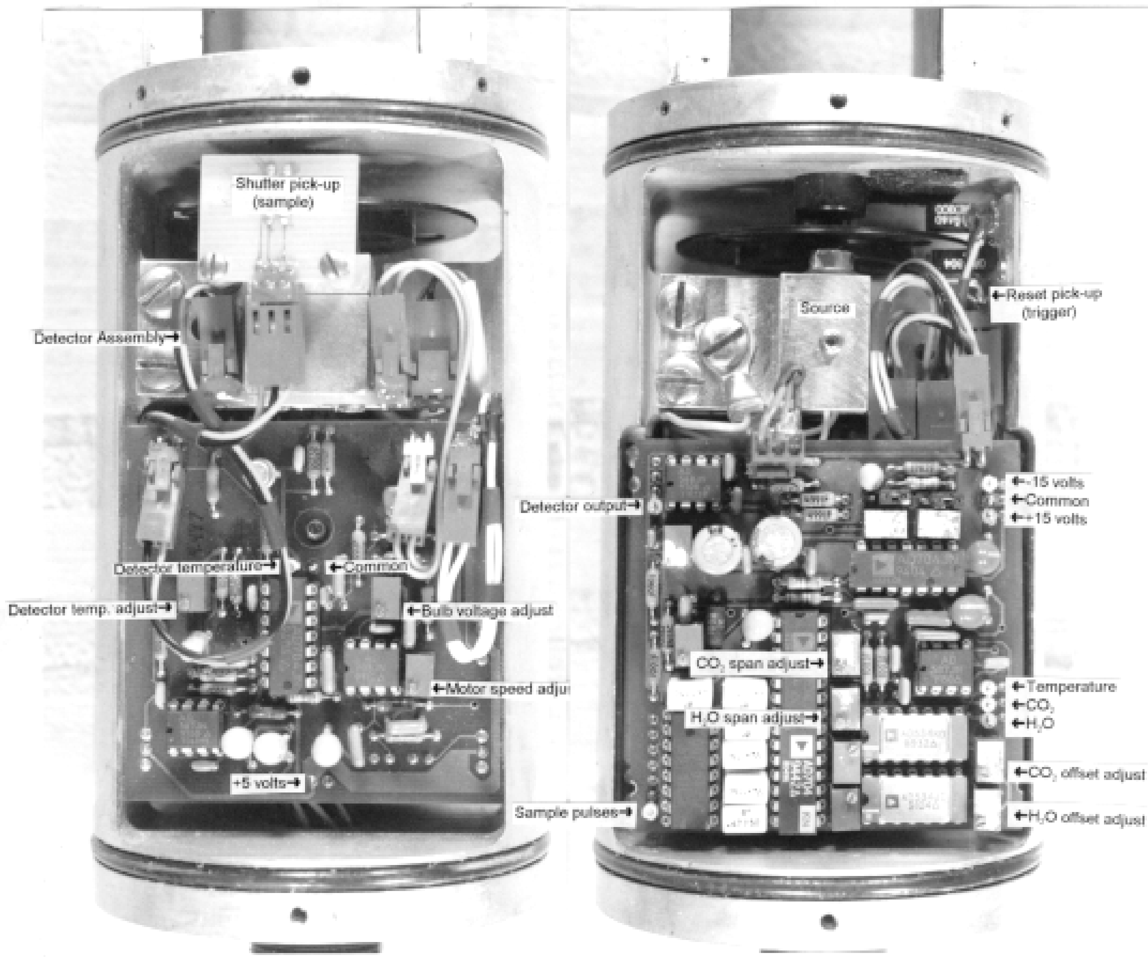
1) Auble, D., Meyers, T.: 1992, ‘An Open Path, Fast Response Infrared Absorption Gas Analyzer for H_2O and CO_2', Boundary-Layer Meteorology 59, 243-256.



IR gas analyzer power supply
Sensor connector
TS2
TS3
Shield
H2O
CO2
Can temperature
Detector output
PS1
PS2
R3
R4
C1
C2
F1
TS1
P1

APPENDIX B

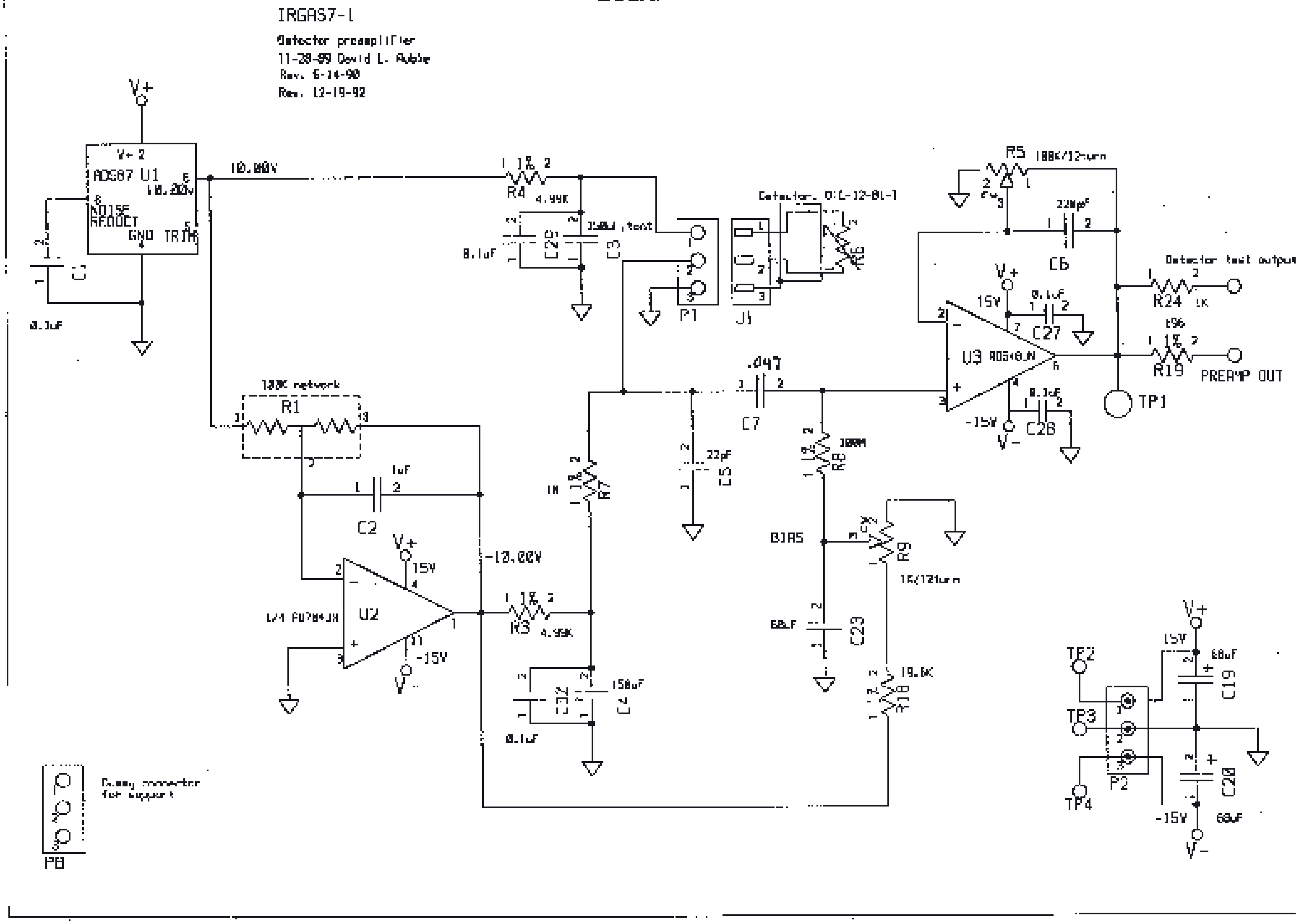
Photos



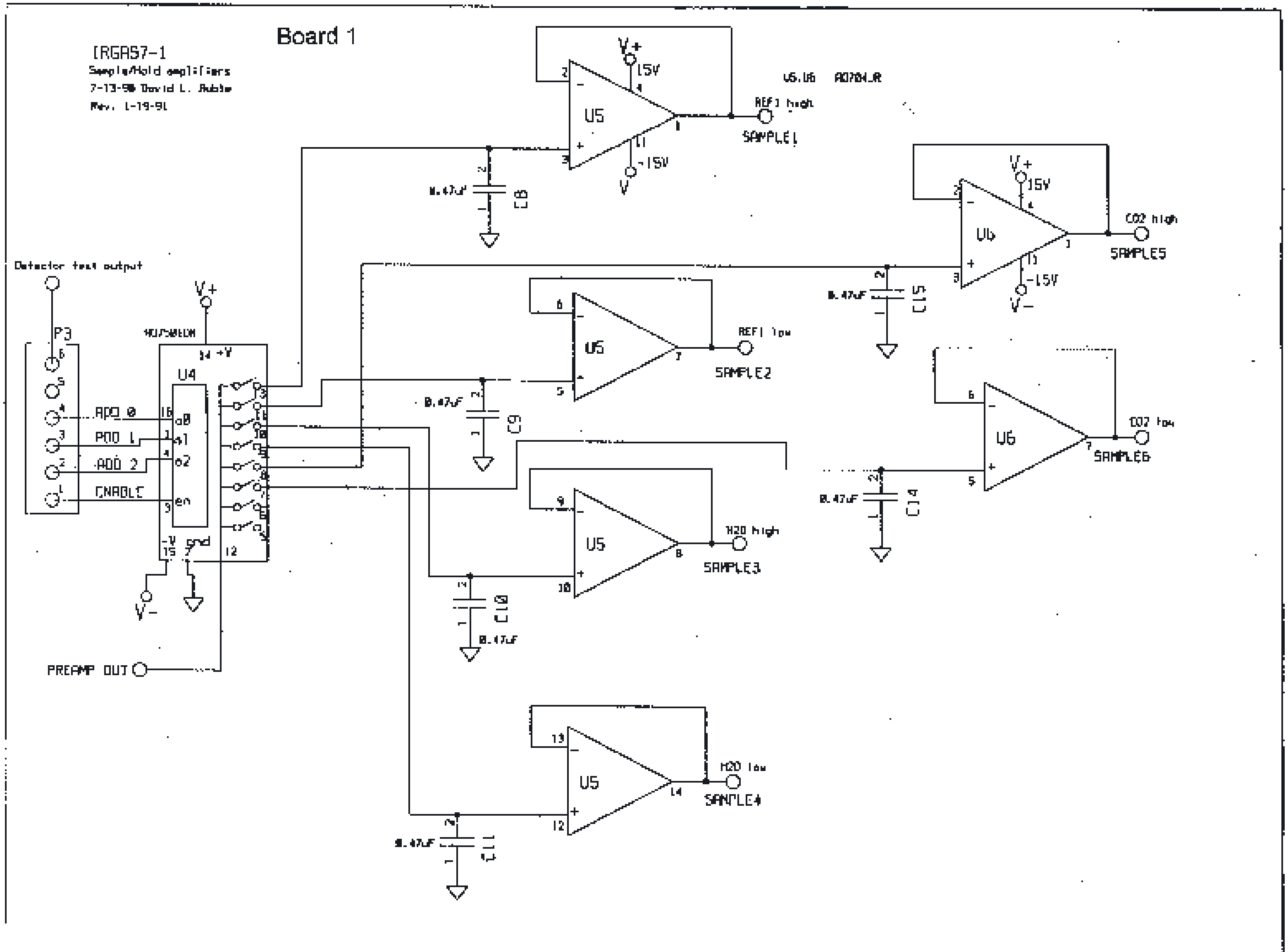
Detector Side
(Board 3)

Source Side
(Board 1)

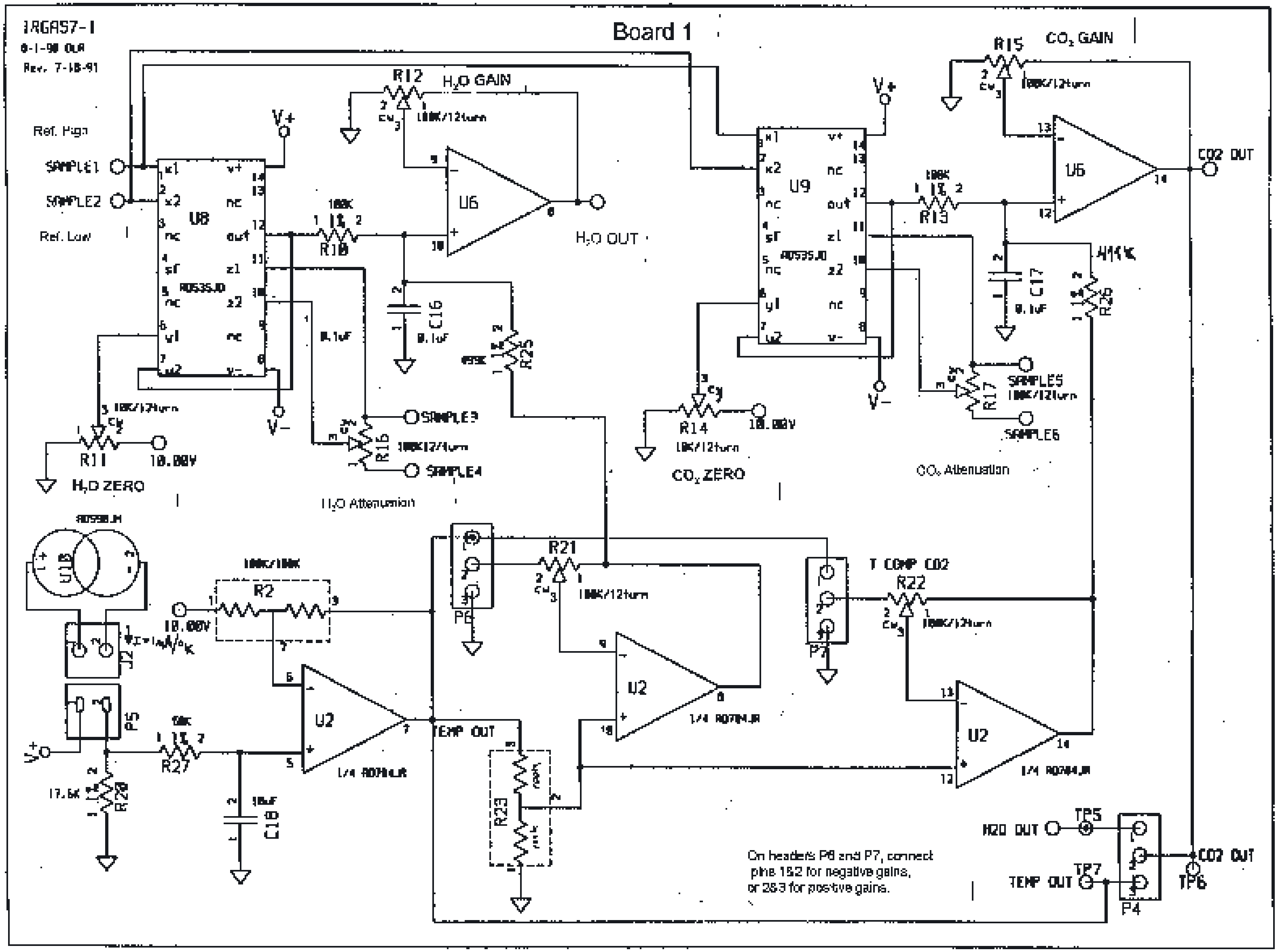
Board 1



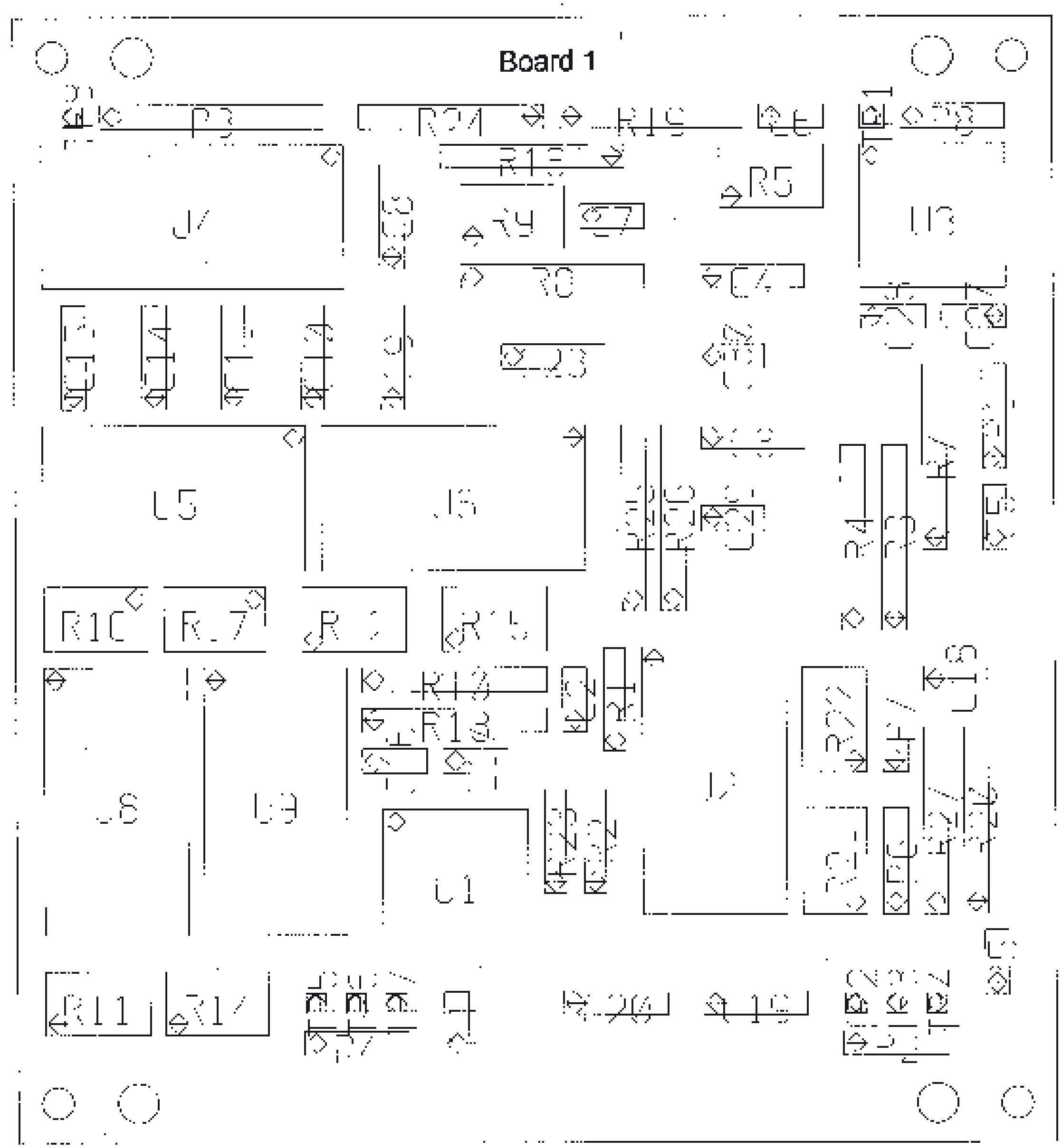
IRGAS7-1
Detector preamplifier
11-28-89 David L. Auble
Rev. 6-14-90
Rev. 12-19-92
ADG07 U1
NOISE REDUCT
GND TRIM
10.00V
R4 4.99K
C3 150uF, test
C29 0.1uF
P1
J1
Detector OTC-32-81-1
R6
R5 100K/12-turn
C6 220pF
U3 AD548JN
15V
-15V
C27 0.1uF
C28 0.1uF
R24 1K
Detector test output
R19
PREAMP OUT
TP1
C7 .047
C5 22pF
R7 1M
R8 100M
BIAS
R9 1K/12-turn
C23 68uF
R10 19.6K
R1 100K network
C2 1uF
U2
LM AD704JN
-10.00V
R3 4.99K
C4 150uF
C32 0.1uF
TP2
TP3
TP4
P2
C19 68uF
C20 68uF
Dummy connector for support
P8



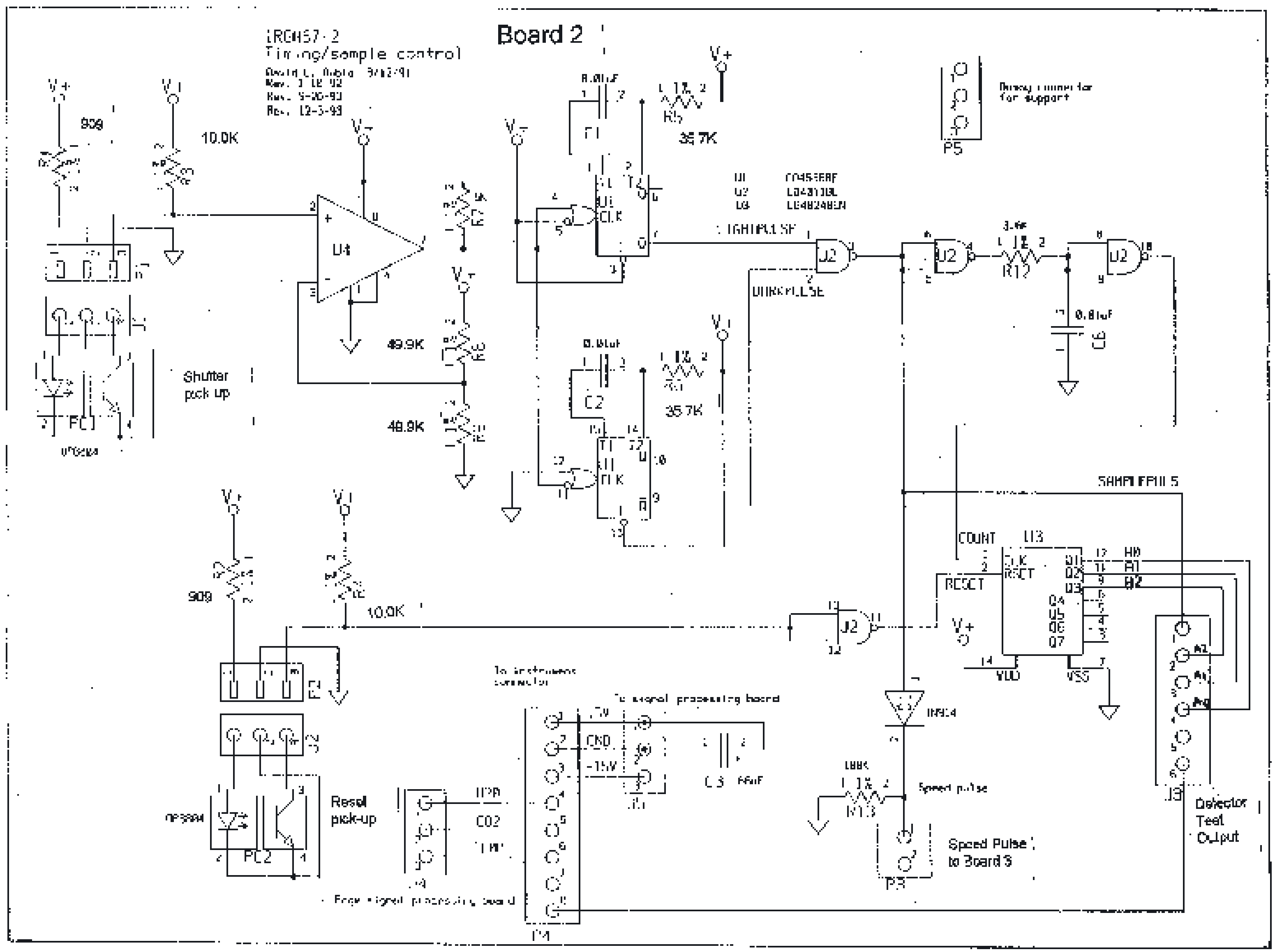
Board 1
IRGA57-1
Sample/Hold amplifiers
7-13-90 David L. Ruble
Rev. 1-19-91
U5,U6 AD704JR
REF1 high
SAMPLE1
CO2 high
SAMPLE5
REF1 low
SAMPLE2
CO2 low
SAMPLE6
H2O high
SAMPLE3
H2O low
SAMPLE4
Detector test output
P3
U4
ADD 0
ADD 1
ADD 2
ENABLE
PREAMP OUT
U5
U6
C8
C9
C10
C11
C14
C15
0.47uF
V+
V-
15V
-15V

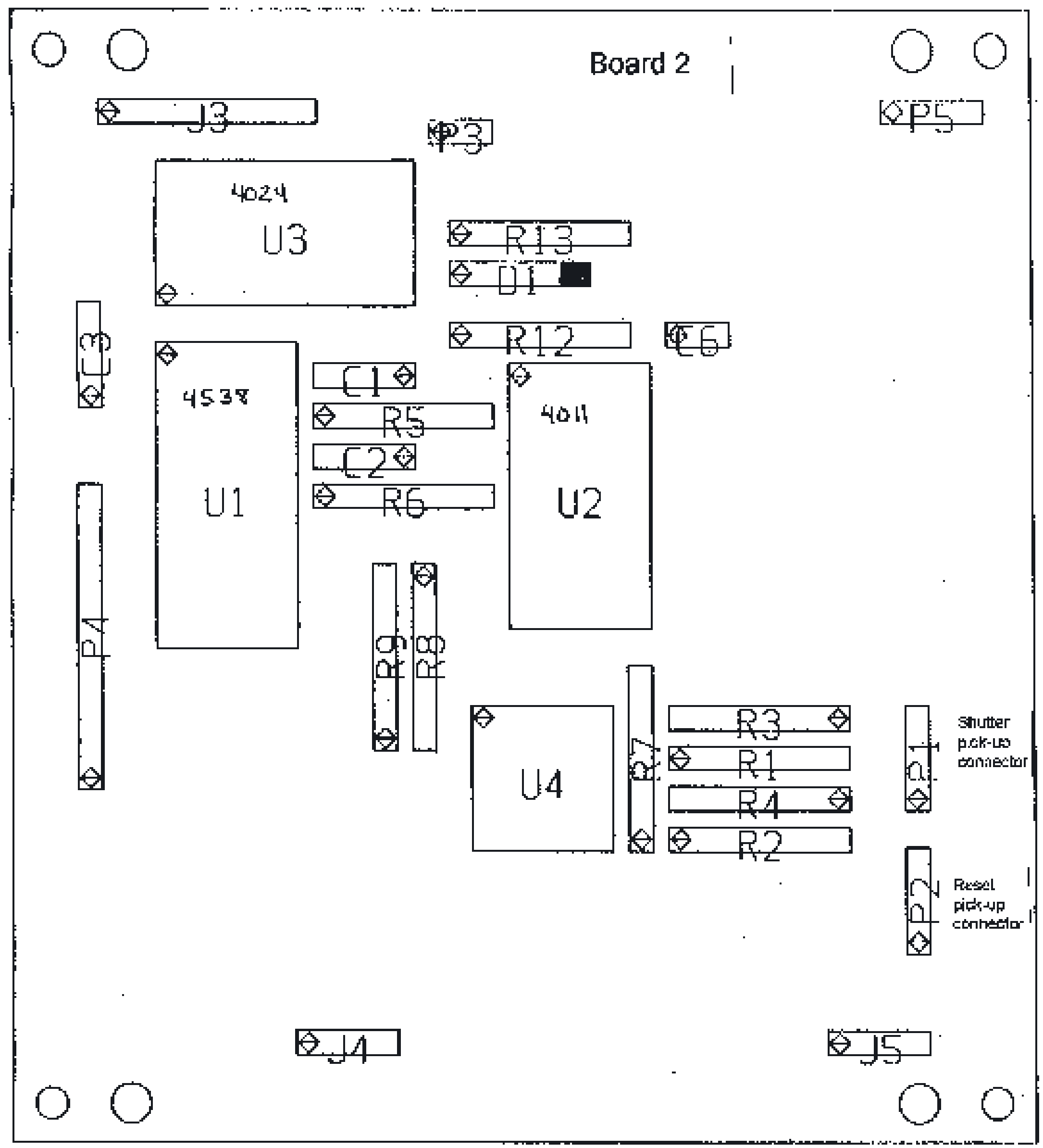


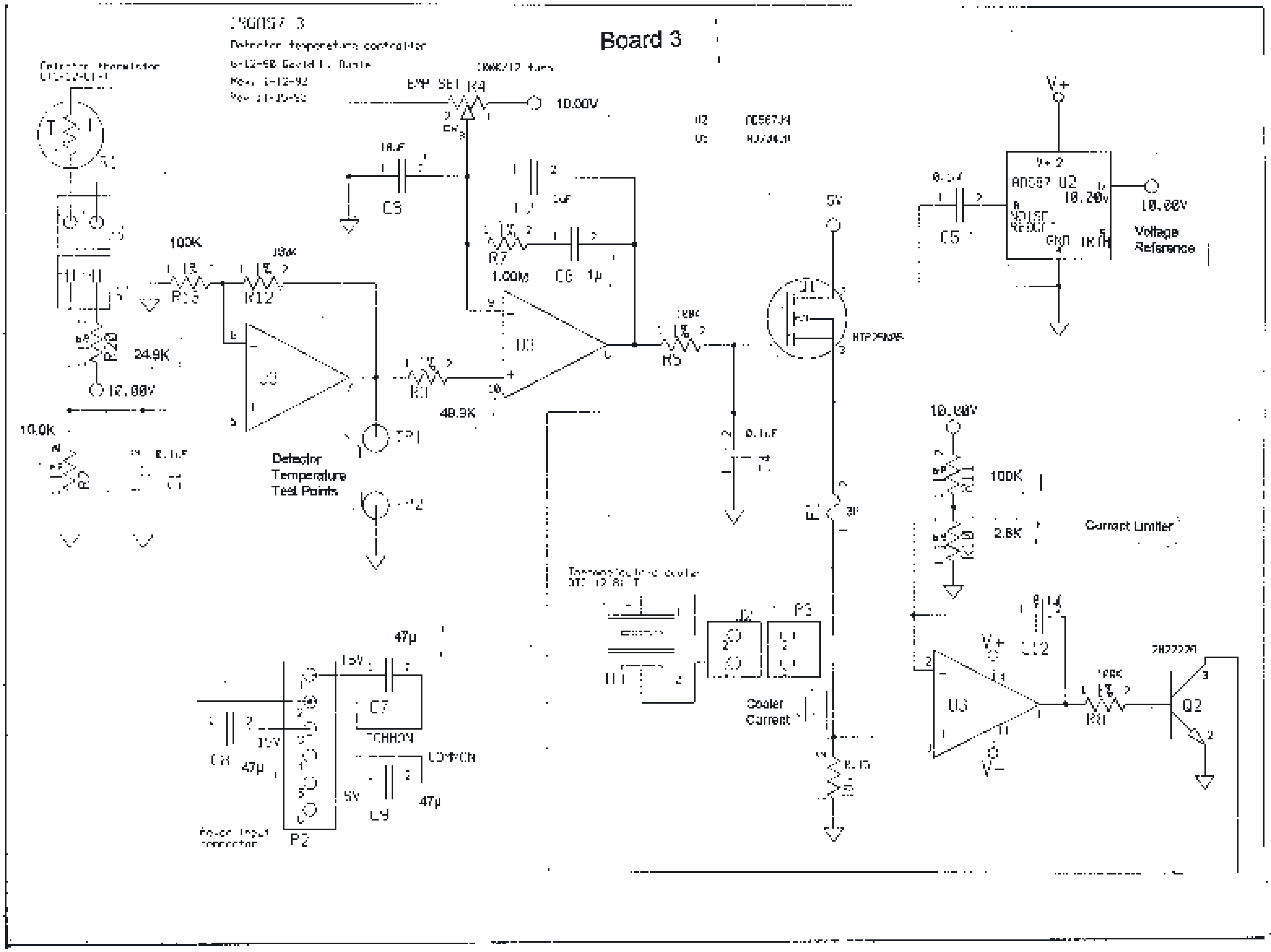
IRGA57-I
8-1-90 OLR
Rev. 7-18-91
Board 1
Ref. High
SAMPLE1
SAMPLE2
Ref. Low
U8
AD535JD
V+
V−
R10
100K
U6
R12
H2O GAIN
100K/12turn
H2O OUT
C16
0.1uF
R25
R11
10.00V
H2O ZERO
R16
SAMPLE3
SAMPLE4
H2O Attenuation
U9
CO2 GAIN
R15
R13
CO2 OUT
C17
R26
R14
10K/12turn
CO2 ZERO
R17
SAMPLE5
SAMPLE6
CO2 Attenuation
U18
J2
P5
R2
100K/100K
R27
R28
17.6K
C18
U2
1/4 AD704JR
TEMP OUT
P6
R21
R23
T COMP CO2
R22
P7
TP5
H2O OUT
TP7
TEMP OUT
TP6
P4
On headers P6 and P7, connect pins 1&2 for negative gains, or 2&3 for positive gains.



Board 1


Board 2
Timing/sample control
Shutter pick up
Reset pick-up
Speed Pulse to Board 3
Detector Test Output
SAMPLEPULSE
COUNT
RESET
DARKPULSE
To signal processing board
From signal processing board
To instrument connector
Dummy connector for support
909
10.0K
49.9K
35.7K
0.01uF
68uF
VDD
VSS
GND
-15V
CO2
Speed pulse
P5
P3
J3
P4

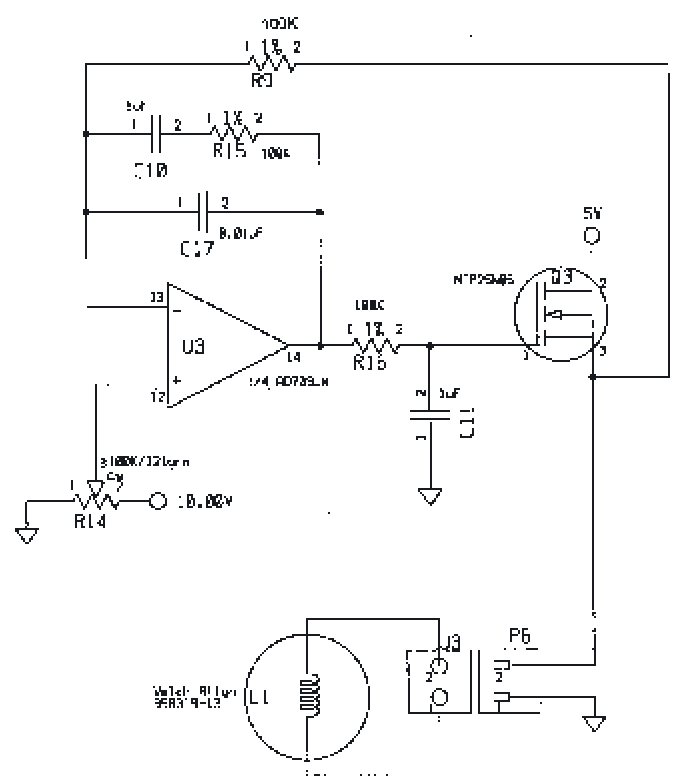

Board 2
J3
P3
P5
4024
U3
R13
D1
R12
C6
C3
4538
C1
R5
C2
R6
U1
4011
U2
P4
R9
R8
U4
R7
R3
R1
R4
R2
P1
Shutter
pick-up
connector
P2
Reset
pick-up
connector
J4
J5


Board 3
Detector temperature controller
Detector Temperature Test Points
Voltage Reference
Current Limiter
Cooler Current
10.00V
5V
V+
V-
R1
R4
R5
R7
R12
R13
R20
C5
C6
C7
C8
C9
C12
U2
U3
Q2
J1
P2
P3
100K
24.9K
10.0K
49.9K
1.00M
2.8K
47µ
TP1
COMMON
RTP25N05
2N2222A

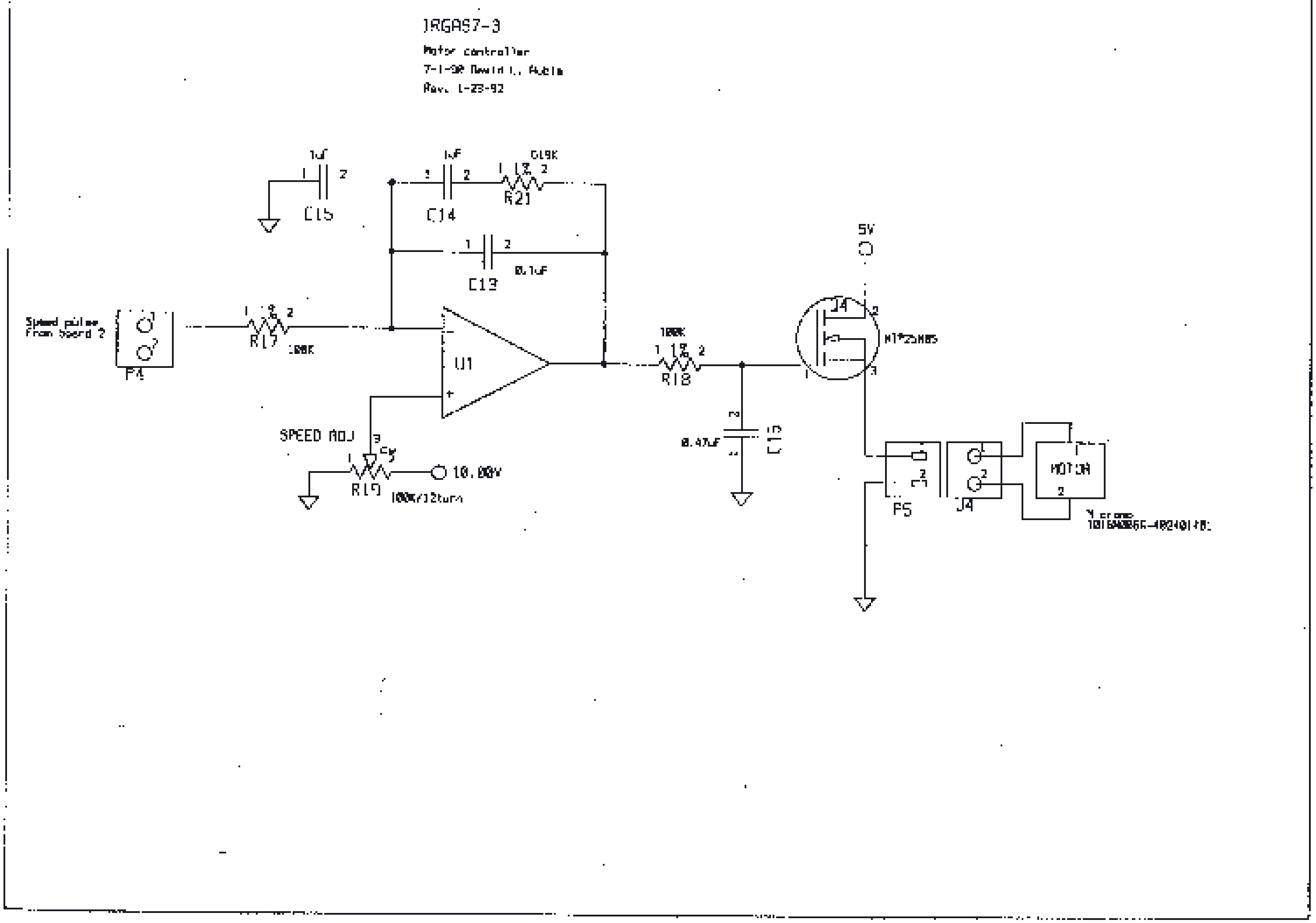
[RGA57-3

Bulb controller/driver
6-23-00 David L. Rubin
Rev. 1-28-02

Board 3

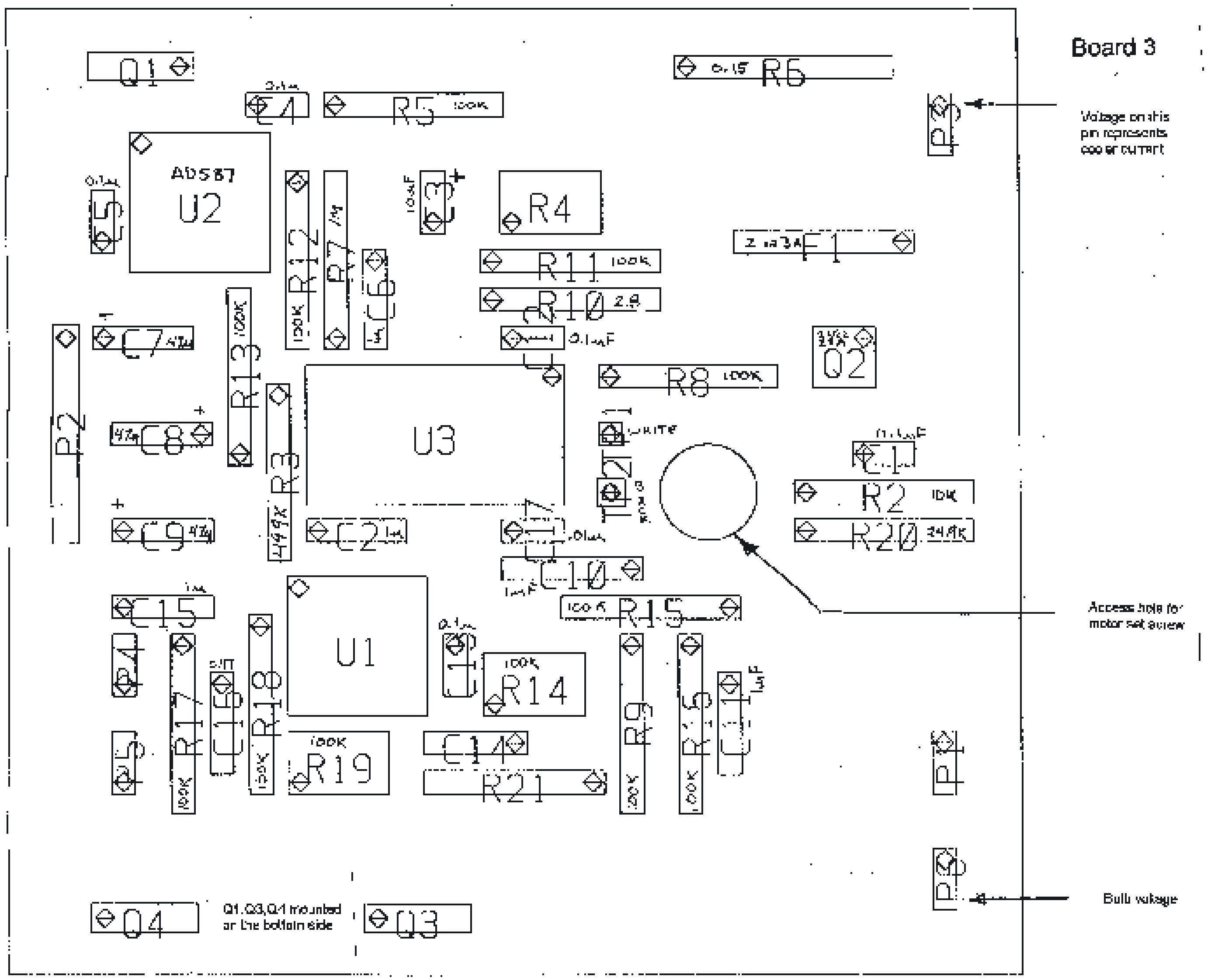


Board 3



JRGAS7-3
Motor controller
7-1-90 David L. Auble
Rev. 1-23-92
Speed pulse
from board 2
P4
R17
100K
1uF
C15
1uF
C14
R21
C13
0.1uF
U1
SPEED ADJ
R19
10.00V
100K/12turn
100K
R18
0.47uF
C15
5V
MTP25N05
P5
J4
MOTOR

Board 3



Voltage on this pin represents cooler current
Access hole for motor set screw
Bulb voltage
Q1,Q3,Q4 mounted on the bottom side
AD587
U2
U3
U1
R4
R5
R6
R8
R11
R10
R2
R20
R12
R7
R13
R3
R14
R15
R9
R17
R18
R19
R21
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C14
C15
C16
F1
Q1
Q2
Q3
Q4
P1
P2
P3

APPENDIX C

Useful Equations

To convert ppm rating of calibration gases to mg/m^3.

where

X	=	the CO_2 concentration rating of the calibration gas
TEMP	=	the temperature of the calibration gas inside the hood
pressure	=	the pressure inside the hood

To convert dew point to mg/m^3 of H_2O:

where

T_d	=	the dew point temperature (˚C) and T_a is the calibration gas temperature (˚C) in the hood

APPENDIX D

Basic Operation and Block Diagram

The IRGA operates on the principal that H2O and CO2 absorb certain wavelengths of infrared radiation, called absorption bands. By passing a beam of infrared radiation through a sample ares, and measuring the attenuation of the radiation in the H2O and CO2 absorption bands, the density of the gases may be measured.

The IRGA actually measures three bands of radiation absorption: The H2O and CO2 absorption bands, and a reference band. The reference band is used to normalize the H2O and CO2 absorption measurements, so that the source intensity changes and non-wavelength specific absorption from dust and dirty optics may be compensated for.

The block diagram shows the basic operation of the IRGA. The infrared source is a halogen bulb. Infrared radiation emitted from the bulb is collimated, and passes through the sample volume, as shown by the dashed lines. It is measured by a thermoelctrically cooled PbSe infrared detector.

The filter wheel in the optical that provides two functions: A chopper to optically turn the source on and off, and a filter selector, to sequentially pass the optical filters for each of the three wave bands in front of the detector. The position of the shutters on the outside of the wheel relative to the filters allows the detector to measure six different values: The radiation levels passing through each of the three optical filters with the shutter open and closed.

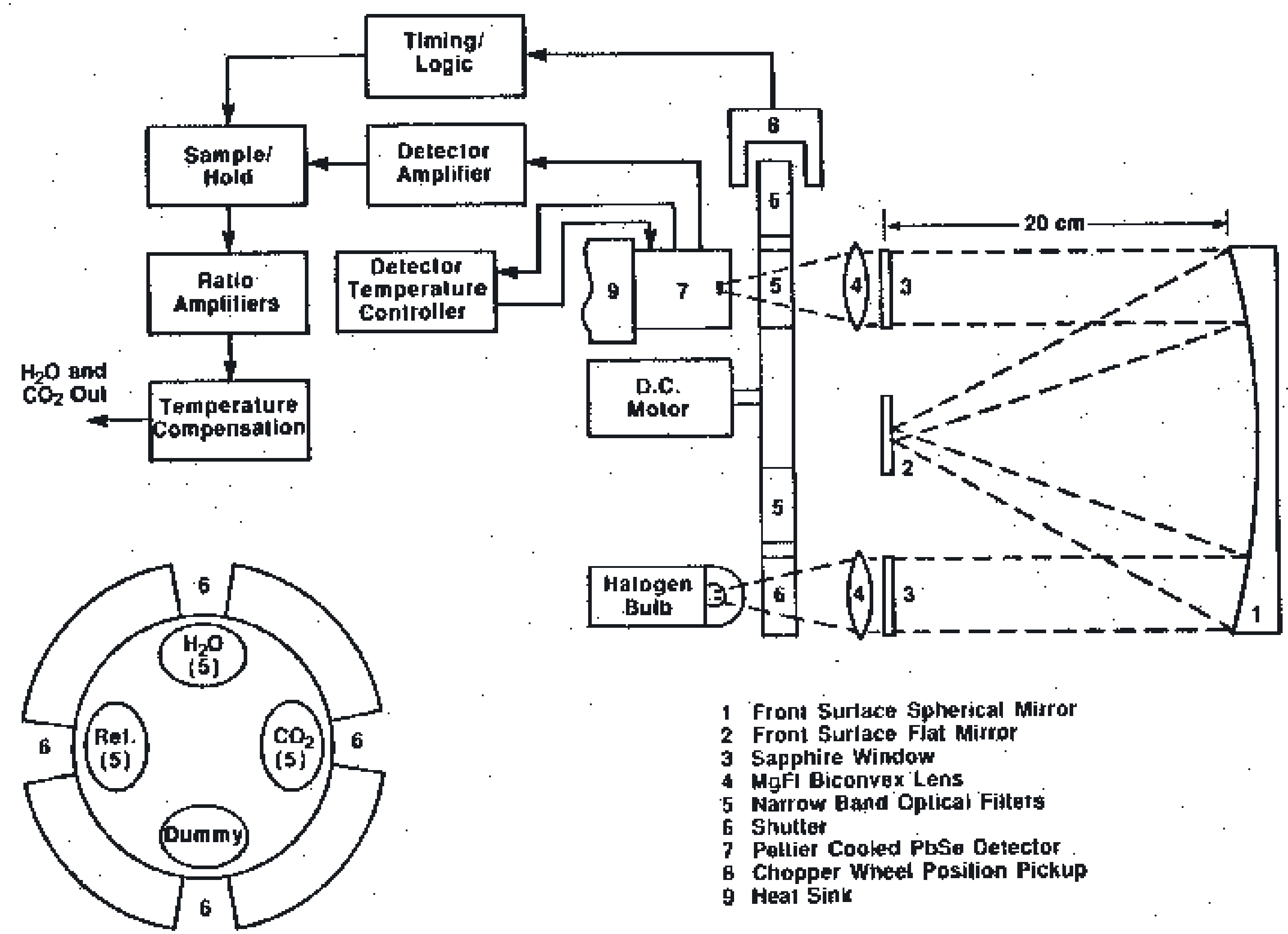
Two optical switchers are used to determine the position of the filter wheel. One switch senses each shutter opening and closing. Timing and logic circuits (Board2) convert the switch outputs to sample commands that control sample/hold amplifiers (Board1). The sample/hold amplifiers samples the voltage levels of the detector amplifier output (Board 1) for each of the six different radiation values.

The H2O and CO2 (shutter open and closed) sampled values are connected to the numerator differential inputs of ratio amplifier. The reference (shutter open and closed) sampled values are connected to the denominator differential inputs of both ratio amplifiers. The ratio amplifiers provide an output offset adjustment input, which is used as the H2O and CO2 instrument output offset adjustment. The output of each ratio amplifier are mixed with individually scalable temperature measurements, providing a linear temperature compensation for offset. H2O and CO2 output span adjustments are made with variable gain amplifiers.

The detector temperature is maintained at about -20˚C by a thermoelectric cooler and feedback thermistor inside the detector TO-8 can. A servo type control loop controls the current to the cooler (Board 3).

The filter wheel speed is regulated by the sample pulses from the timing/logic board. A servo type control loop controls the voltage to the motor spinning the filter wheel (Board 3).

ATDL-M 90/1230



Front View of Chopper Wheel

APPENDIX E

Chopper Motor Replacement

If it is determined that the chopper motor is worn out, it may be replaced.

1) Remove the finned cover.

2) Disconnect the detector and temperature sensor connectors from Board 1 and carefully remove Board 1 by lifting it up.

3) Remove the two photo pick-up connectors from Board 2.

4) Remove the four screws securing Board 2 to the chassis, and lift Board 2 up far enough that the connectors on the bottom of the board may be reached.

5) Disconnect the connectors from the bottom of Board 2.

6) Loosen the set screw securing the chopper motor. This screw is accessed through the hole in Board 3.

7) Remove the chopper motor by pulling it backwards away from the chopper wheel and disconnect the motor connector from Board 3.

8) Transfer the motor cable/connector to the new motor, noting proper polarity. The positive (red) wire is marked near the terminals on the motor with a plus sign.

9) Install the new motor. A short piece of silicon tubing is used as a flexible coupling to attach the motor shaft to the filter wheel axle. Be sure that the tubing is not pushed too far onto the motor shaft, or it will rub against the face of the motor. Make sure that the whole assembly spins freely, and the flexible coupling is secure and clear of any internal cables before tightening the motor set screw.

10) Reinstall Board 2. Make sure all of the connectors on the top and bottom of Board 2 are attached. The motor replacement may be tested now by applying power to the instrument. Make sure that the filter wheel spins at the proper frequency (approximately 45Hz). Proper operation may be checked by stopping the filter wheel momentarily, and letting it restart. It should spin up to a higher than normal RPM, and then slow to the proper speed.

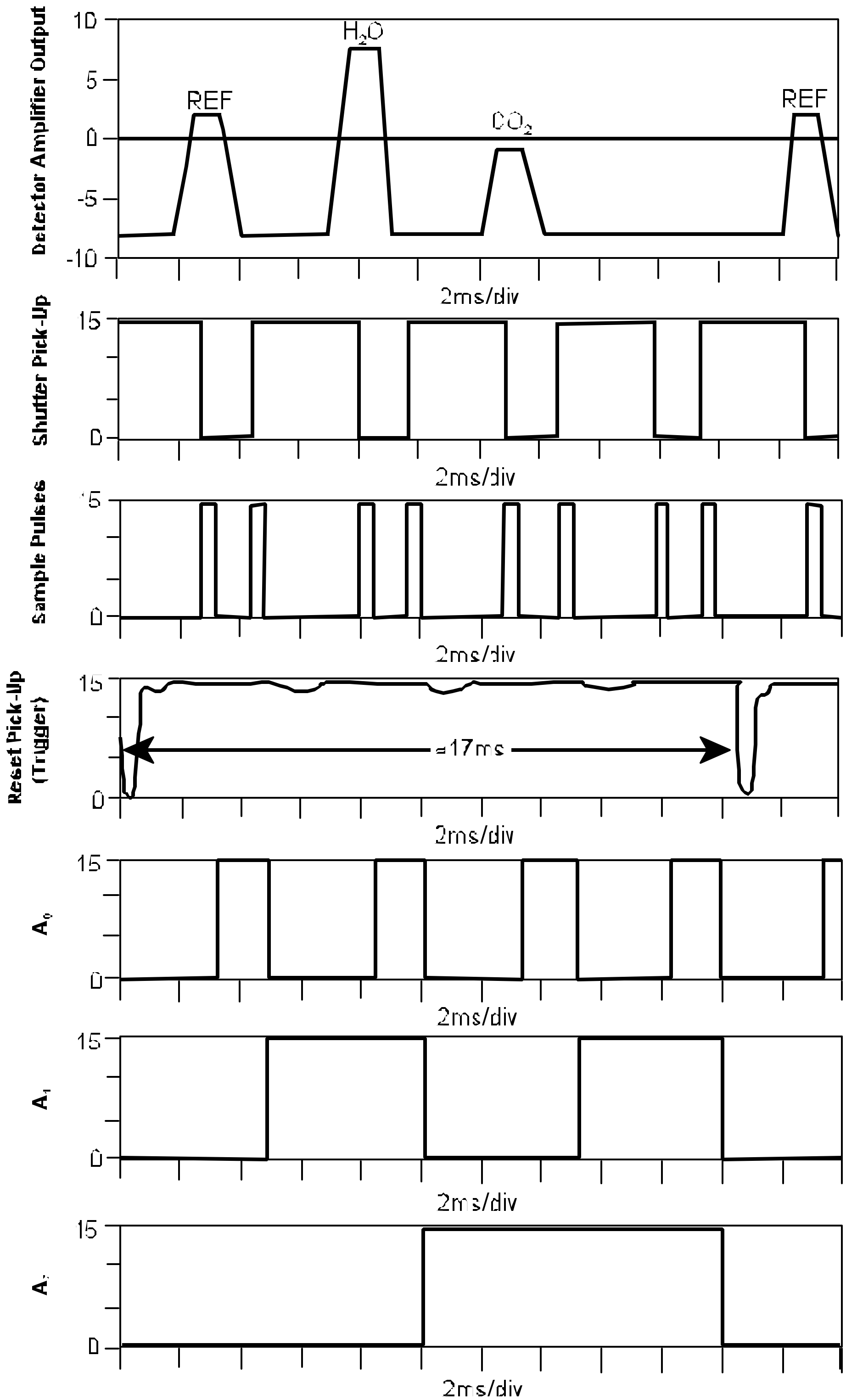
11) Replace Board 1 being sure to properly align the board to board connectors between Board 1 and Board 2.

12) Reattach the detector and temperature sensor connectors.

13) Replace the finned cover.

APPENDIX F

Timing Diagram



APPENDIX G

Optical Alignment

Place a piece of white paper over the 1/2" mirror between the two sapphire windows. Power up the instrument. Adjust the bulb distance from the lens until the filament image is in focus. Check to make sure the collimated beam is completely in the field of 2" mirror. The bulb holder may be adjusted in one axis by loosening the screws and sliding it side to side. The other axis can be adjusted by either shimming the bulb holder up with thin brass or aluminum shim stock, or lowering it by grinding or milling the bottom of the bulb holder. Adjust the bul holder position and the rod lengths (by loosening the locking screws turning them) until the filament image is centered on the 1/2" mirror, and least 95% of the collimated beam is in the filed of the 2" mirror. Apply a sealant to the locking screws inside the chassis to prevent water from entering through the rod threads. Tighten the locking screws at both ends of each rod. Recheck the alignment.

At this point, half of the optical system is aligned. Move the white paper screen form the 1/2" mirror to the detector window. Check to see if the circular light pot is mostly centered over the detector window. If it is not, the 1/2" mirror will need to be realigned. Remove the 1/2" mirror by pulling up from the bottom through the access hole son either side of the mounting well. Clean any adhesive fro the mirror and the well, and reinstall it with an RTV adhesive. Adjust the alignment of the 1/2" mirror until the collimated spot is centered over the detector window. Make sure that at least 95% of the collimated beam is within 2" mirror. If it is not, the rods will have to be readjusted and the entire procedure reiterated. A cyanoacrylate (“super glue”) may be used to tack the mirror in place while the slow adhesive cures.